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Monostatic and bistatic HF radar cross section analysis of large vessels using FEKO

Symon K. Podilchak

Defence R&D Canada – Ottawa

Contract Report
DRDC Ottawa CR 2010-262
April 2011

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Abstract

Monostatic and bistatic Radar Cross Sections (RCS) of Canadian Coast Guard Ship Teleost and cargo-container vessel named Bonn Express are simulated using FEKO commercial electromagnetic simulation software. A good agreement is achieved between the simulated values and the measured values supplied by DRDC Ottawa, at the radar frequency of 4.1 MHz. With confidence in these FEKO models, the effect of pitch, roll and freighter loading was then investigated to account for such practical situations in oceanic environments.

Résumé

La surface équivalente radar (SER) de radars monostatiques et bistatiques à bord du navire de la Garde côtière canadienne (NGCC) *Teleost* et du transporteur de conteneurs de fret *Bonn Express* a fait l’objet de simulations à l’aide du logiciel commercial de simulation électromagnétique FEKO. Une bonne concordance est obtenue entre les valeurs simulées et les valeurs mesurées fournies par RDDC Ottawa, à la fréquence radar de 4,1 MHz. Ces modèles FEKO inspirant confiance, on a alors étudié l’effet du tangage, du roulis et de la charge des navires pour tenir compte de telles situations pratiques en milieu océanique.

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Executive summary

Monostatic and bistatic HF Radar Cross Section Analysis of Large Vessels Using FEKO (U)

Symon L. Podilchak and Hank Leong; DRDC Ottawa CR 2010-262; Defence R&D Canada – Ottawa, December 2010.

Introduction or background:

One of the key parameters required in the simulation of HF Surface Wave Radar (HFSWR) performance is the Radar Cross Sections (RCS) of the targets of interest. DRDC Ottawa had an interest in the performance of bistatic HFSWR. As part of his Master's thesis works (2008), LCdr. Ryan Solomon incorporated and then refined the set of models previously developed by Leong and Wilson[1] at DRDC Ottawa for the Canadian Coast Guard Ship Teleost and cargo-container vessel named Bonn Express to study the High Frequency range bistatic RCS values of complex structures using FEKO commercial electromagnetic simulation software. This report extends the work in LCdr. Solomon's thesis to include additional RCS investigations. Specifically, numerical simulations are provided to investigate the varied changes of the RCS values due to practical situations in oceanic environments. The varied simulations can be described as follows:

- RCS simulations of the Teleost vessel for varied pitch and roll positions; and
- RCS simulations of the Bonn Express vessel for varied loading.

In the absence of any information on the possible extent of pitch and roll of the Teleost vessel, we assume that the bow of the ship can be rotated by up to 15 degrees, and the port side of the ship can be rotated by up to 10 degrees.

Results:

The effect of vessel pitch was first investigated by rotating the bow of the Teleost model upwards by 5, 10 and 15 degrees. The effect of ship roll was also investigated by rotating the port side of the same model upwards by 5 and 10 degrees. In both cases, simulations show that there are noticeable differences between the monostatic RCS values of the rotated model and the upright model. In the frequency range of 1-20 MHz over all the aspect angles, a difference of as much as 15 dB could be observed. More detailed analysis of the results has been presented in RadarCon 2009 (S. Podilchak, H. Leong, R. Solomon and Y. Antar, "Radar Cross Section Modeling of Marine Vessels in Practical Oceanic Environment for High-Frequency Surface-Wave Radar", IEEE RadarCon 2009, Pasadena, CA, May 2009).

[1] H. Leong and H. Wilson., "An Estimation and Verification of Vessel Radar Cross Sections for HFSWR", IEEE Antenna and Propagation Magazine, 48, No. 2, pp. 11-16, Apr 2006.

The model of Bonn Express was then modified to account for different levels of loading and to include a fore- and after-mast. A better agreement is found between the simulated values using the modified model and the measured values supplied by DRDC Ottawa, at the radar frequency of 4.1 MHz, when the vessel is modeled as fully loaded.

Sommaire

Monostatic and Bistatic HF Radar Cross Section Analysis of Large Vessels Using FEKO (U)

Symon L. Podilchak and Hank Leong; DRDC Ottawa CR 2010-262; Defence R&D Canada – Ottawa, December 2010.

Introduction

L'un des paramètres clés requis dans la simulation du rendement du radar hautes fréquences à ondes de surface (HFSWR) est la surface équivalente radar (SER) des cibles d'intérêt. RDDC Ottawa s'est intéressé au rendement du radar HFSWR bistatique. Dans le cadre de ses travaux de thèse de maîtrise (2008), le capc Ryan Solomon a intégré et raffiné le jeu de modèles qu'avaient mis au point Leong et Wilson[2] à RDDC Ottawa à l'intention du navire de la Garde côtière canadienne (NGCC) *Teleost* et du transporteur de conteneurs de fret *Bonn Express* en vue de l'étudie des valeurs SER de radars bistatiques à structure complexe dans la gamme des hautes fréquences à l'aide du logiciel commercial de simulation électromagnétique FEKO. Le présent rapport élargit les travaux de la thèse du capc Solomon par l'ajout d'autres études de la SER. Plus précisément, des simulations numériques sont fournies en vue de l'étude des diverses modifications des valeurs de la SER attribuables à des situations pratiques en milieu océanique. Les diverses simulations peuvent être décrites comme suit :

- simulations de la SER à bord du *Teleost* pour l'étude de l'effet de la variation du tangage et du roulis;
- simulations de la SER à bord du *Bonn Express* pour l'étude de l'effet de la variation de la charge.

En l'absence de données sur l'étendue possible du tangage et du roulis du *Teleost*, nous supposons que la proue du navire peut pivoter d'au plus 15 degrés et que le côté bâbord du navire peut pivoter d'au plus 10 degrés.

Résultats

On a étudié l'effet du tangage du navire tout d'abord en faisant pivoter la proue du modèle du *Teleost* vers le haut de 5, de 10 et de 15 degrés. On a aussi étudié l'effet du roulis du navire en faisant pivoter le côté bâbord du même modèle vers le haut de 5 et de 10 degrés. Dans les deux cas, les simulations montrent des différences perceptibles entre les valeurs de la SER de radar monostatique du modèle pivoté et du modèle droit. Dans la gamme de fréquences 1-20 MHz à tous les angles d'aspect, une différence d'au plus 15 dB a pu être observée. Une analyse plus détaillée des résultats a été présentée lors de la conférence RadarCon 2009, organisée par l'IEEE à Pasadena (CA) en mai 2009 (S. Podilchak, H. Leong, R. Solomon et Y. Antar,

[2] H. Leong et H. Wilson, *An Estimation and Verification of Vessel Radar Cross Sections for HFSWR* (estimation et vérification des valeurs de la surface équivalente radar dans le cas du radar HFSWR), revue *Antenna and Propagation* de l'IEEE, 48, n° 2, p. 11-16, avril 2006.

Radar Cross Section Modeling of Marine Vessels in Practical Oceanic Environment for High-Frequency Surface-Wave Radar (modélisation de la surface équivalente radar (SER) de radars hautes fréquences à ondes de surface à bord de navires maritimes en situation pratique en milieu océanique).

On a alors modifié le modèle du *Bonn Express* pour tenir compte de différents niveaux de charge et inclure un mât de misaine et un mât arrière. On a constaté une meilleure concordance entre les données simulées obtenues à l'aide du modèle modifié et les valeurs mesurées fournies par RDDC Ottawa, à la fréquence radar de 4,1 MHz, lorsque le navire est modélisé comme ayant une charge complète.

Radar Cross Section Analysis of Naval Vessels Using FEKO

This report illustrates recent developments of radar cross section (RCS) simulations performed by Symon Podilchak, supervised by Hank Leong and Dr. Yahia M. M. Antar. Modeling, analysis and RCS simulations were conducted using FEKO and MATLAB.

Previous work was conducted by LCdr. Ryan Solomon during his Master's Thesis, RCS modeling of complex structures in high frequency (HF) surface-wave radar SWR applications, at the Royal Military College of Canada. This report extends the work of LCdr. Solomon's thesis to include additional RCS investigations. Specifically, numerical simulations are provided to investigate the varied changes of RCS values due to practical situations in oceanic environments. The varied simulations can be described as follows:

- RCS simulations of the Teleost vessel for varied pitch and roll positions;
- RCS simulations of the Teleost and Bonn Express vessels for varied loading.
- Simulations were conducted for bow to stern incident angles (with 5^{o} increments).
- Only the vertical scattered field components were analyzed.
- Simulations were completed from1 -20 MHz (with a 1MHz increment).
- A perfect ground plane (PEC) was used to model the horizontal plane of the ocean.
- Orientations of incident field angles with respect to the standard ship orientation (port, starboard, bow and stern) are shown in Fig. 1.
- Photographs of the Teleost and Bonn Express vessels are shown in Figs. 2 and 3.

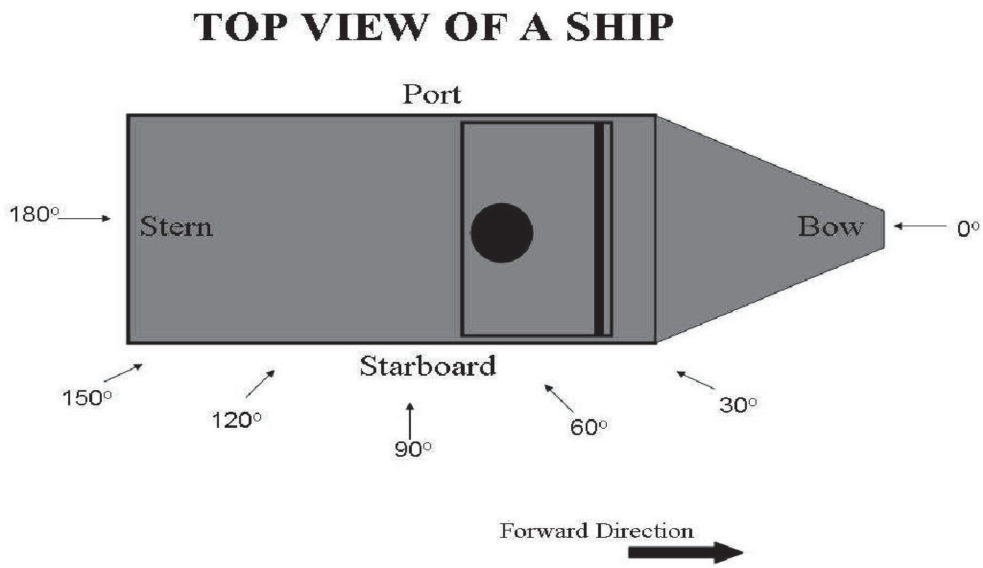

Figure 1: Top view of a standard ship and angles of incident f elds referenced to the port, starboard, bow and stern.

Figure 2: Photograph of Teleost Vessel for the Canadian Coast Guard.

Figure 3: Photograph of the Bonn Express Freighter Vessel with Container Loading.

Simulation I - Base Teleost Model

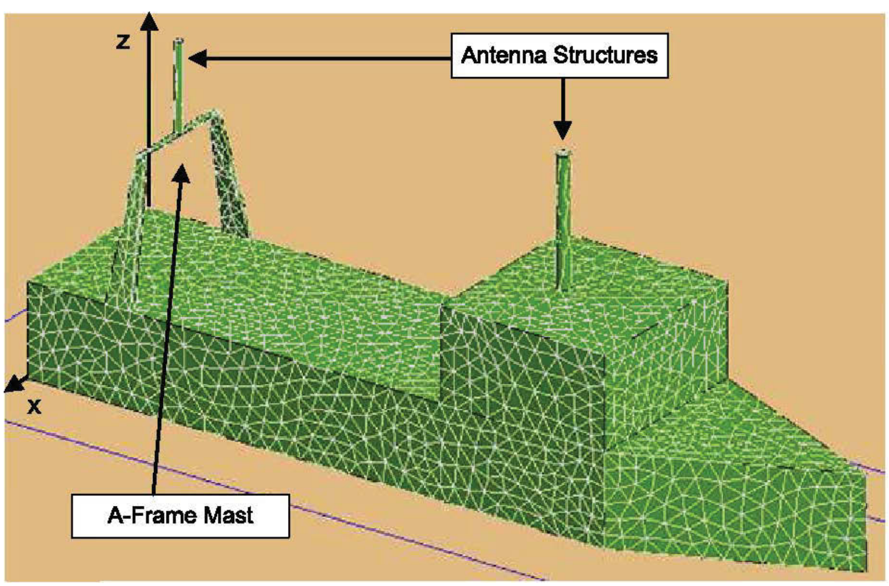

Figure 4: Teleost base model simulation with A-frame mast and antenna structures.

To have confidence in the results presented in this work, simulations were compared to measured RCS values for the Teleost vessel at 4.1 MHz. Results are shown in Fig. 5 and a deviation less than 1.25 dB is observed. Since such a reasonable agreement between measured and simulated values is observed, additional investigations using similar methodologies may also be valid.

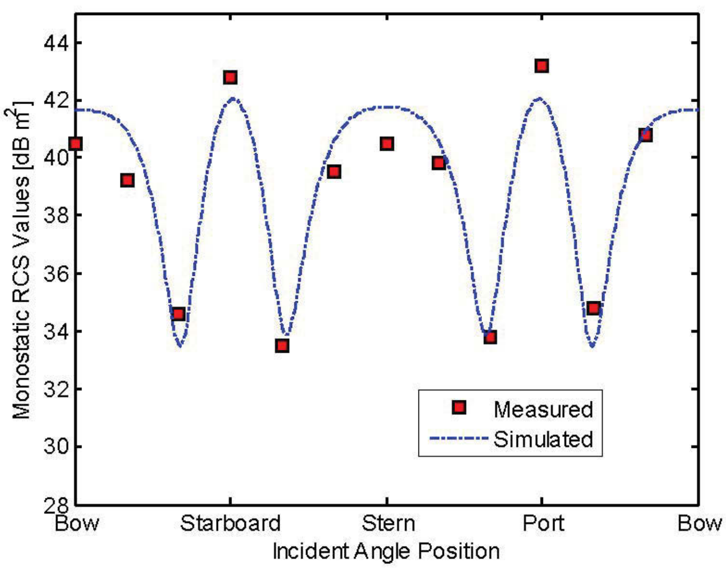

Figure 5: Comparison of Measured and Simulated RCS Values for Teleost at 4.1 MHz.

It is interesting to note that a null at broadside is observed at 7 MHz as shown in Fig. 6. This result is expected since the vessels of interest are Rayleigh and resonant scatters. Specifically, resonant scatterers are generally of the order of one-half to 10 wavelengths in size. For instance, at 7 MHz, $\lambda/2$ = 21.4 m which is approximately equal to the height of the modeled A-Frame mast and antenna structures (24 m). To investigate this effect further, additional simulations were completed for the Teleost vessel without the antenna structures. The simulated vessel is shown in Fig. 7 and results are shown in Fig. 9. Then, a third simulation was conducted without the A-Frame mast and antenna structures. As expected

the null is not observed due to the reduction of scatter size. The modeled vessel is shown in Fig. 8 and results are shown in Fig. 10.

In addition, bistatic RCS values were determined for broadside incidence (90^o) on the Starboard side of the Teleost. The model shown in Fig. 4 was used for the simulations. A PEC was used to model the horizontal air-ocean interface.

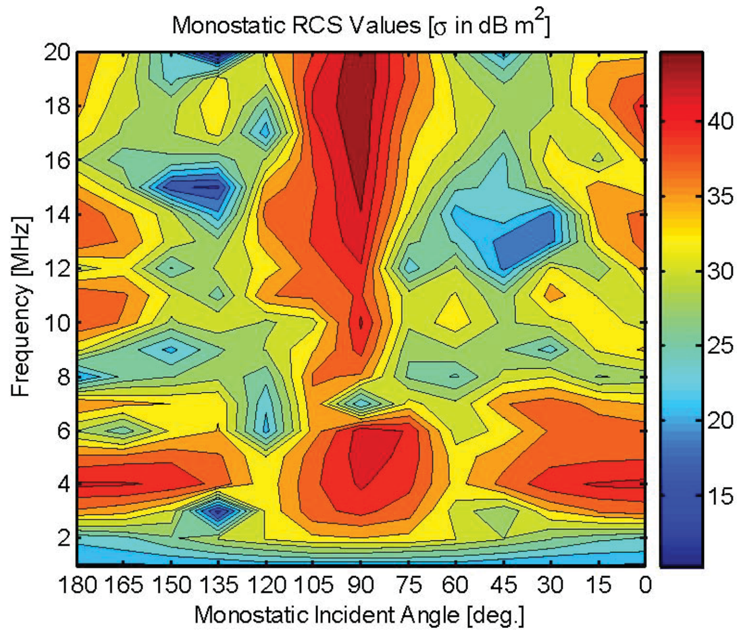

Figure 6: Simulated Monostatic RCS returns for the base model shown in Fig. 4.

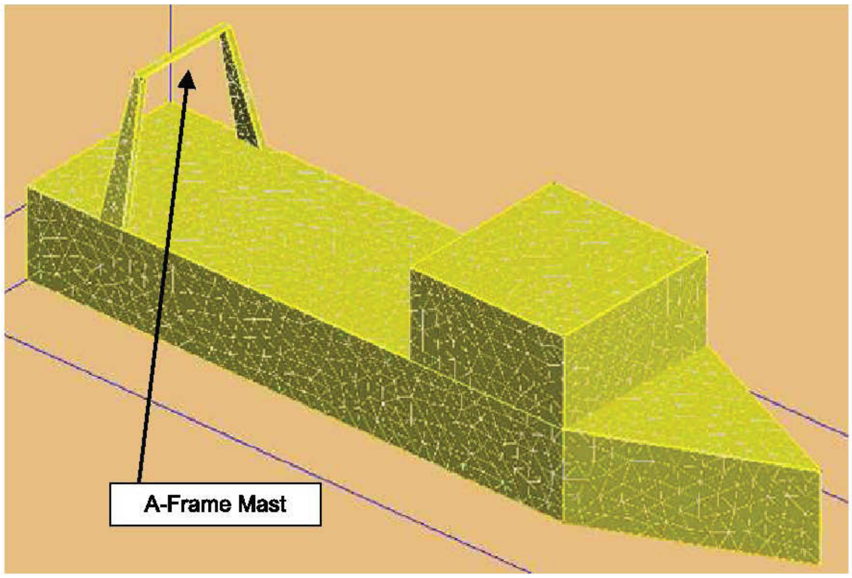

Figure 7: Teleost base model simulation without antenna structures.

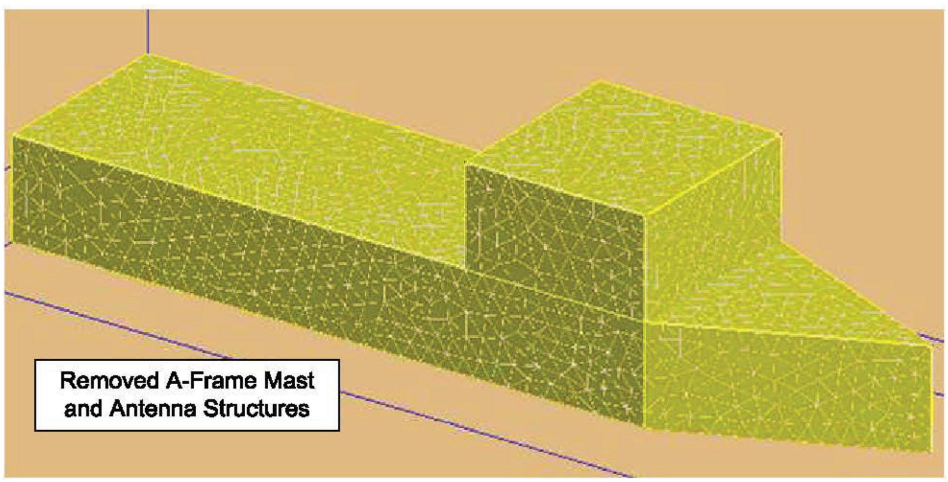

Figure 8: Teleost base model simulation without A-Frame and antenna structures.

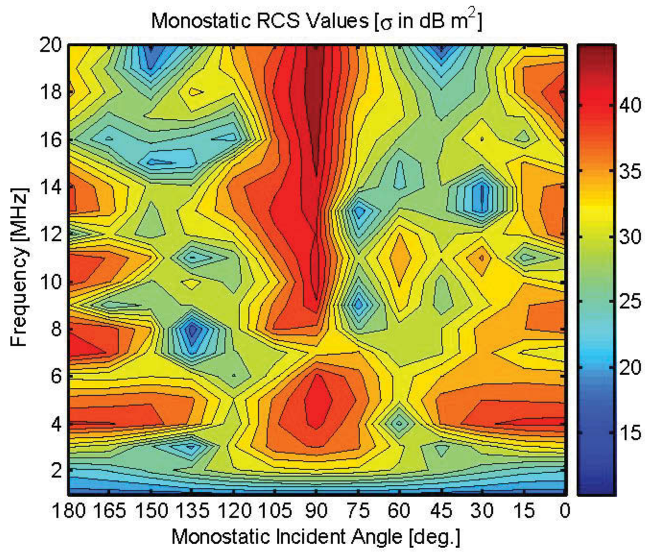

Figure 9: Simulated RCS values of Teleost base model without the antenna structures (Fig. 7).

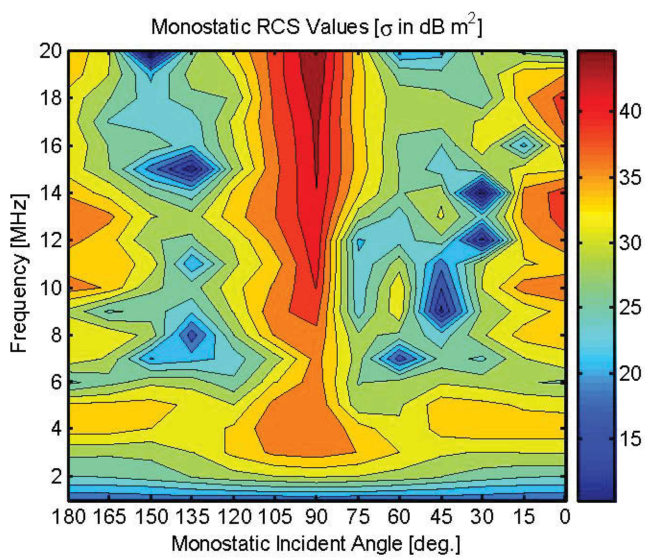

Figure 10: Simulated RCS values of the Teleost base model without the A-Frame mast and antenna structures (Fig. 8). As expected, the scatterer has a reduced size eliminating the resonance effect.

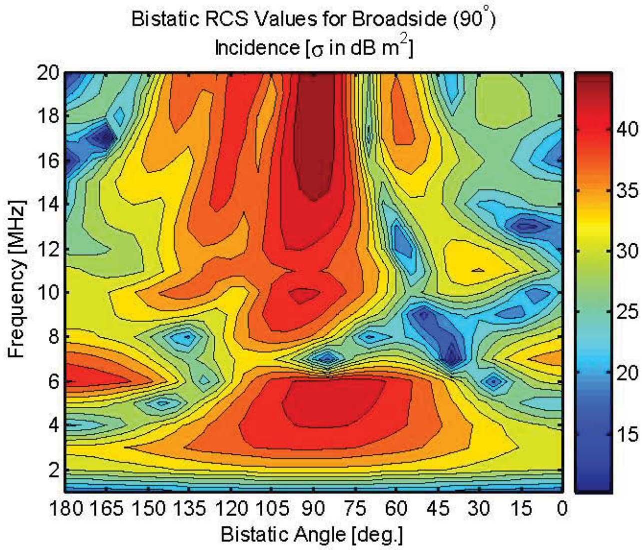

Figure 11: Simulated bistatic RCS values with broadside incidence (90°) for the Teleost base model with antenna structures and A-Frame Mast (Fig. 4).

Simulation II - Upward Rotation of Bow

The second set of simulations investigated the effect of rotating the bow of the Teleost base model upwards (by increments of five degrees) about the origin. Fig. 12 illustrates such a pitch configuration. Monostatic RCS values are shown in Fig. 13 for a 5^o rotation away from the $\hat{y}$-axis towards the $\hat{z}$ direction. The difference between (or normalization to) Simulation I and Simulation II is also shown in Fig. 14. Specifically, the contour plot was determined by the RCS values from Simulation II minus the RCS values from the base model, Simulation I. Figs. 14 -17 illustrate an analogous difference computation with 10^o, 15^o and 25^o rotations.

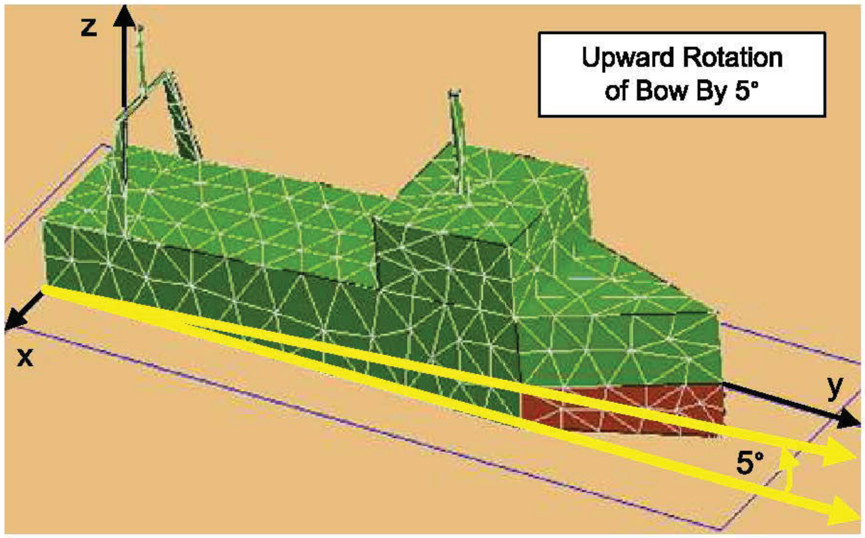

Figure 12: Teleost base model with a 5^{o} upward rotation of the bow.

Such comparisons can illustrate the variance in RCS values due to environmental changes in an oceanic environment. The varied rotations could be caused from a seawater wave or an unforeseen threat. Thus knowledge of such variances from a baseline model could be useful if the vessel of interest is under some unwanted or unknown distress.

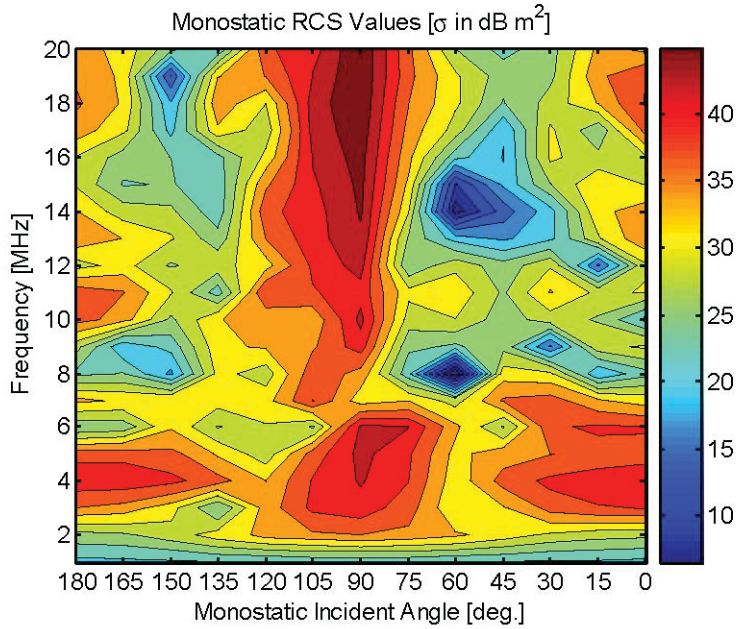

Figure 13: RCS values with a 5^{deg} rotational lift.

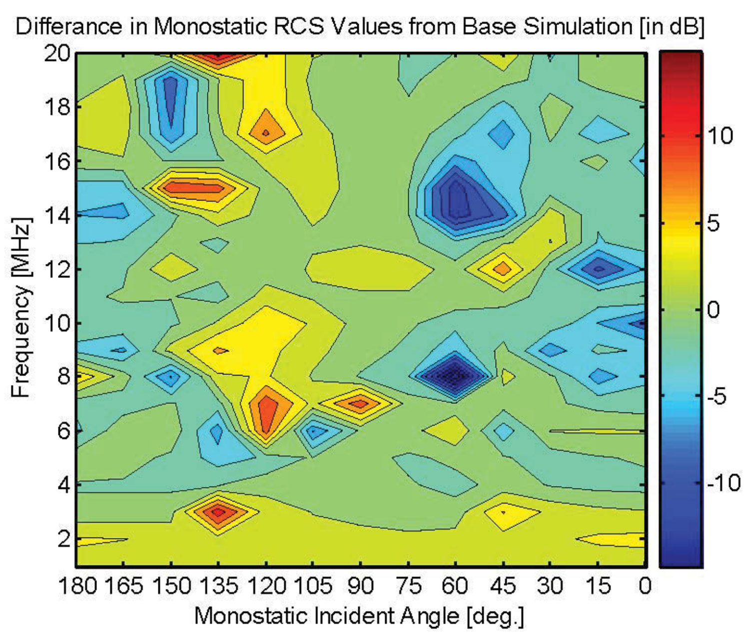

Figure 14: Difference from base simulation I ($\sigma_{5^\circ}/\sigma_{base}$ in dB).

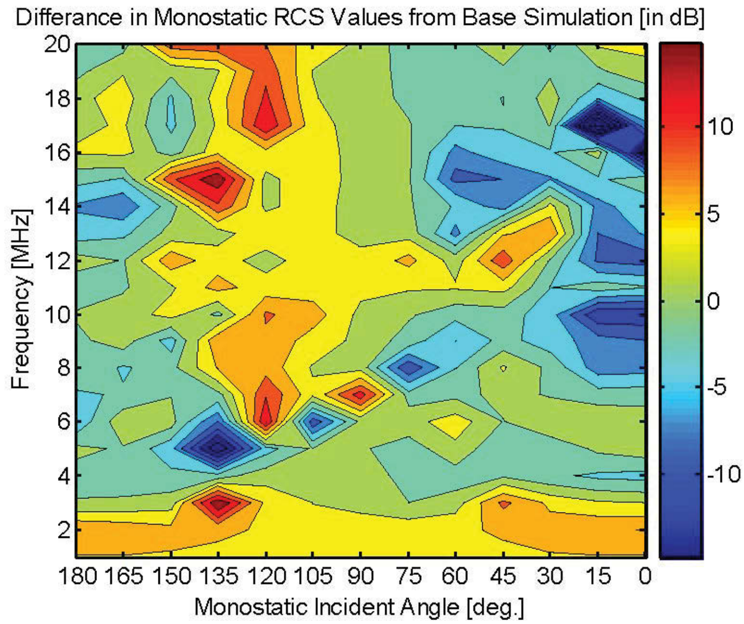

Figure 15: Difference from base simulation I ($\sigma_{10^\circ}/\sigma_{base}$ in dB).

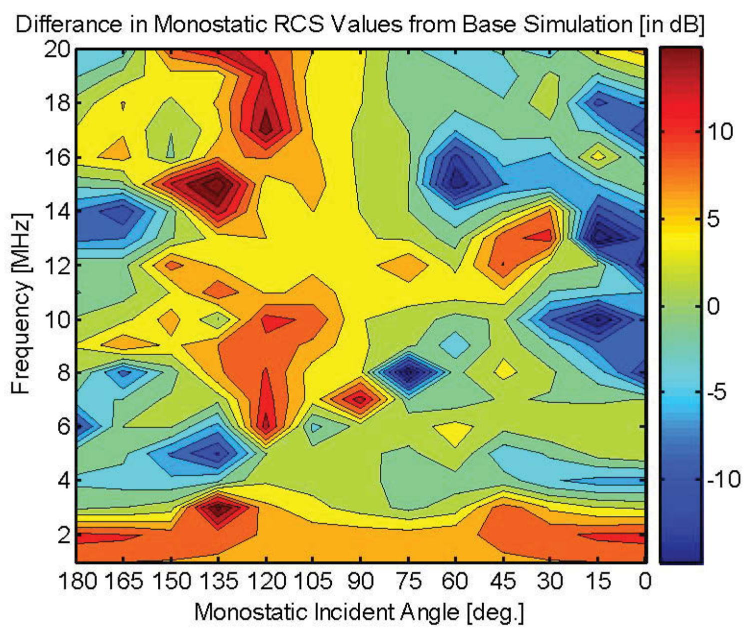

Figure 16: Difference from base simulation I ($\sigma_{15^\circ}/\sigma_{base}$ in dB).

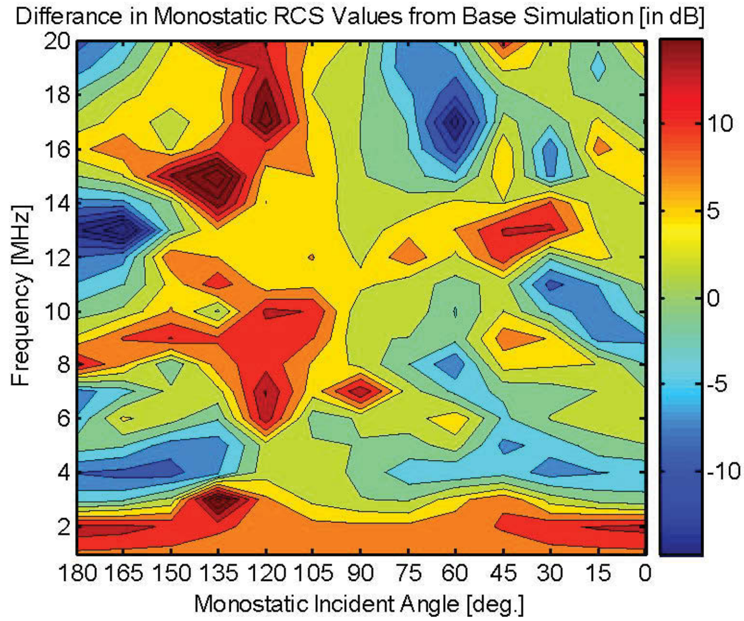

Figure 17: Difference from base simulation I ($\sigma_{25^\circ}/\sigma_{base}$ in dB).

Simulation III - Upward Rotation of Port

The third set of simulations investigated the effect of rotating the port side of the Teleost base model in increments of five degrees about the origin. Fig. 18 illustrates such a pitch configuration.

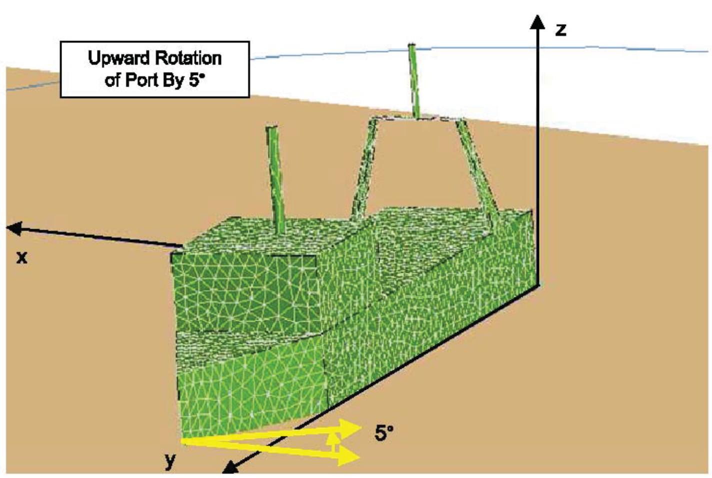

Figure 18: Teleost base model with a 5° upward rotation of the port.

The monostatic RCS values are shown in Fig. 19 for a five degree rotation. Normalization to the base model is also shown in Figs. 20 and 21 for the 5^o and 10^o role positions.

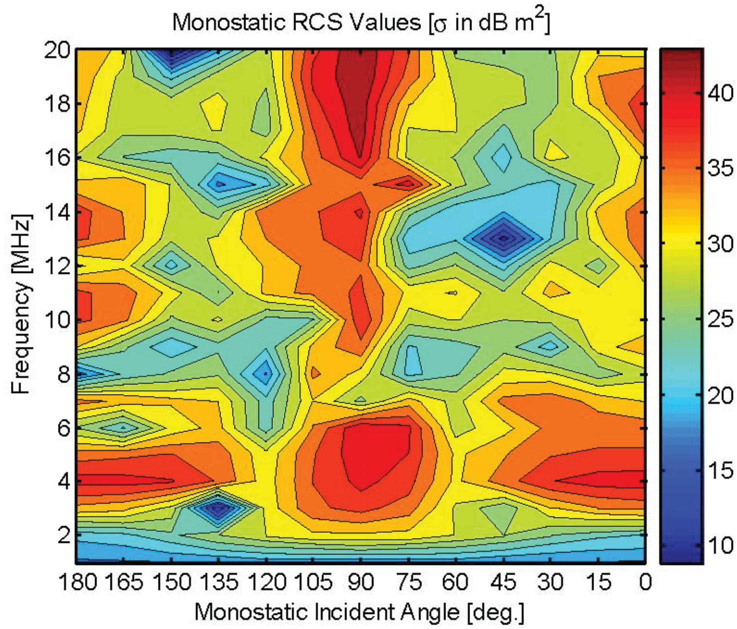

Figure 19: RCS values with a 5^{deg} rotational lift.

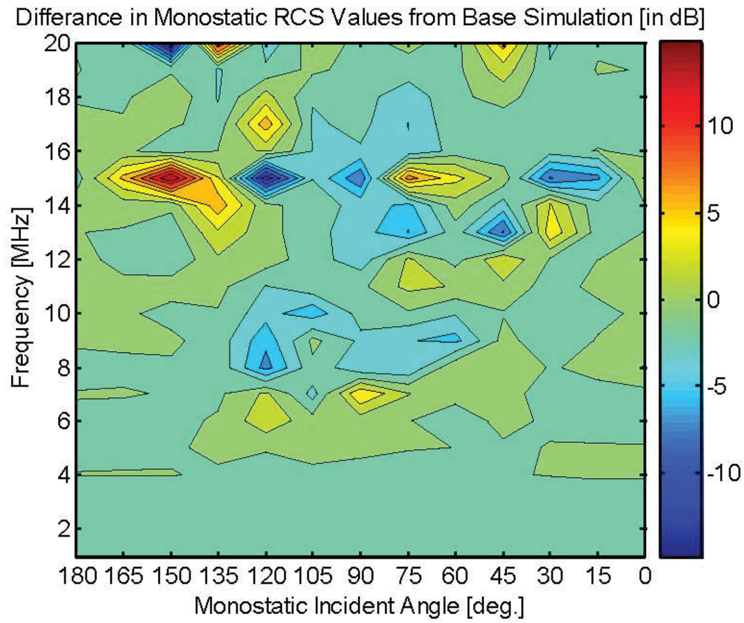

Figure 20: Difference from base simulation I ($\sigma_{5^\circ}/\sigma_{base}$ in dB).

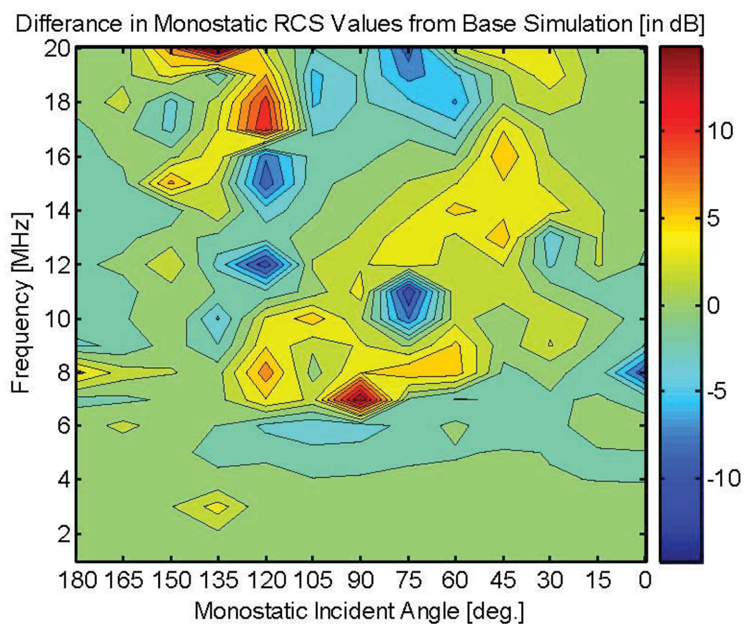

Figure 21: Difference from base simulation I ($\sigma_{10^\circ}/\sigma_{base}$ in dB).

Simulation IV - Upward Rotation of Starboard

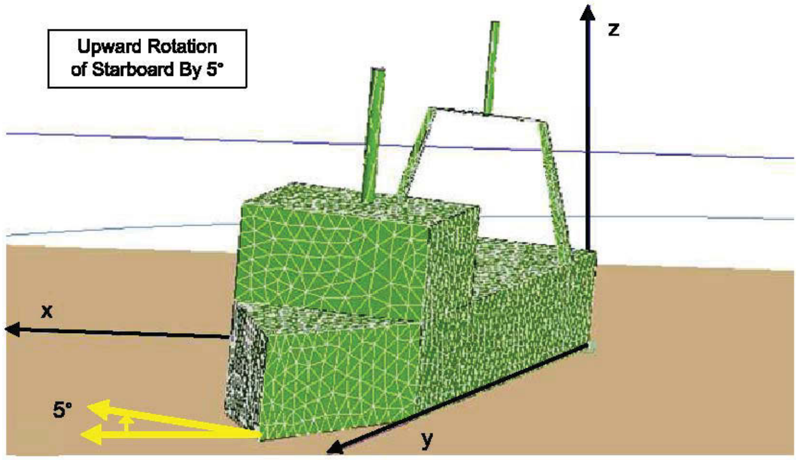

Figure 22: Teleost base model witha 5^{o} upward rotation of the starboard.

The fourth set of simulations investigated the effect of rotating the starboard side of the Teleost base model in a single increment of five degrees about the origin (Fig. 22). The monostatic RCS values are shown in Fig. 23. The normalization to the base simulation results is also shown in Fig. 24.

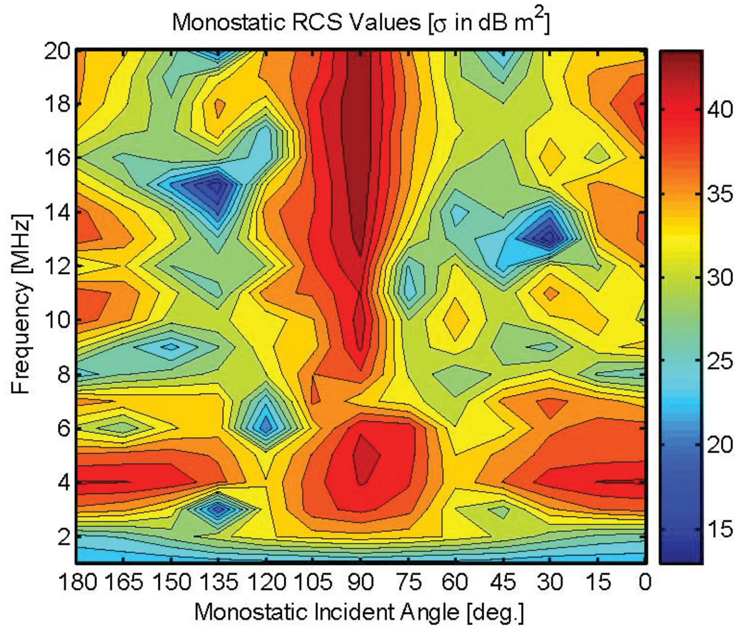

Figure 23: RCS values with a $5^{\deg}$ rotational lift.

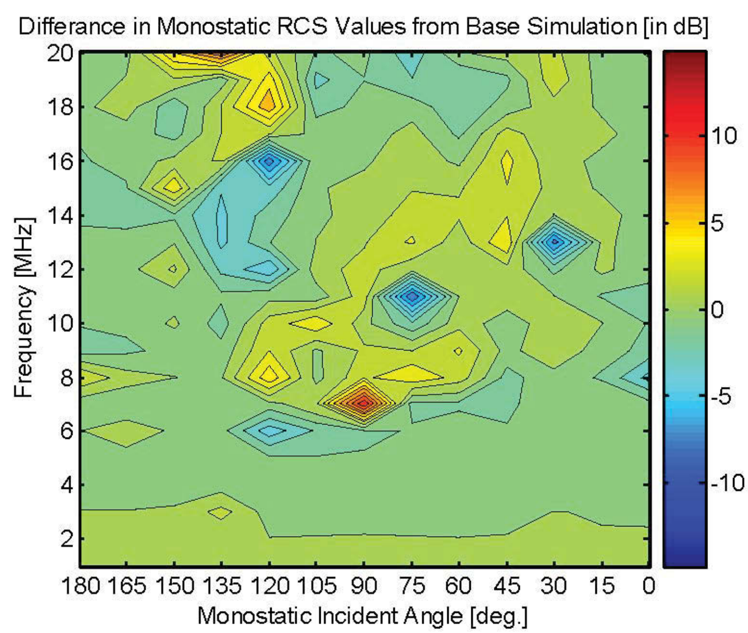

Figure 24: Difference from base simulation I ($\sigma_{5^\circ}/\sigma_{base}$ in dB).

Simulation V - Increased Teleost Payload

The fifth set of simulations investigated the effect of loading the ship and its resulting RCS values by moving the base Teleost model below the ground plane level in sequential increments (2, 3 and 4 m). Essentially, if the ship had increased weight (by loading) the ship itself would be further immersed in the water by displacement. Thus by moving the ship in the negative $\hat{z}$ direction by incremental steps, this effect can be studied. The normalized (to the base simulation) results are shown in Figs. 25 -27.

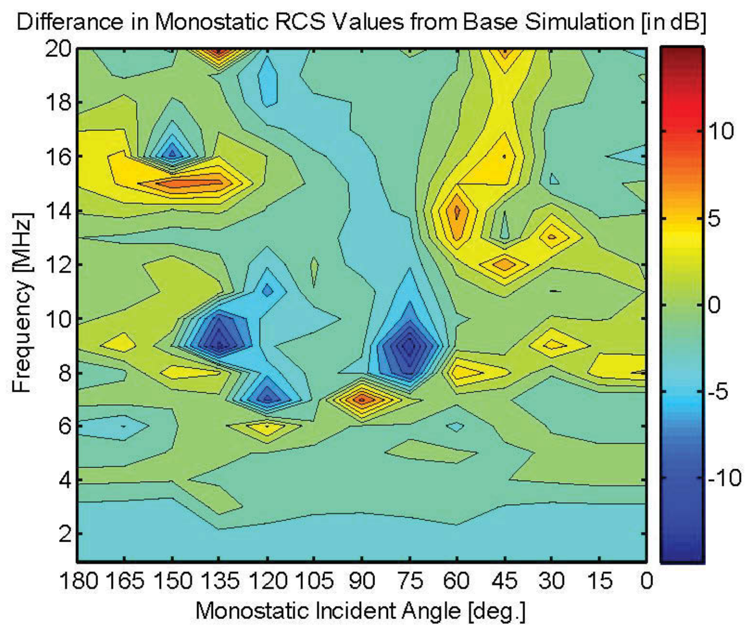

Figure 25: Difference from base simulation I ($\sigma_{2\,below}/\sigma_{base}$ in dB).

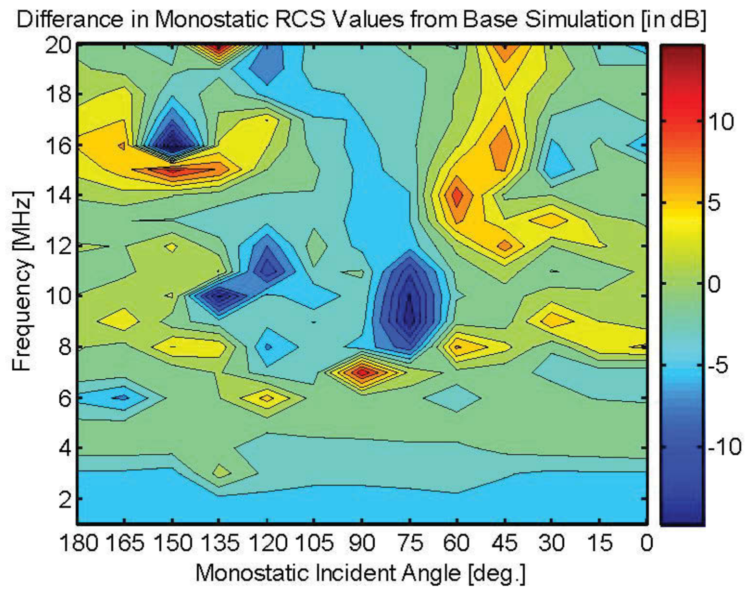

Figure 26: Difference from base simulation I ($\sigma_{3\,below}/\sigma_{base}$ in dB).

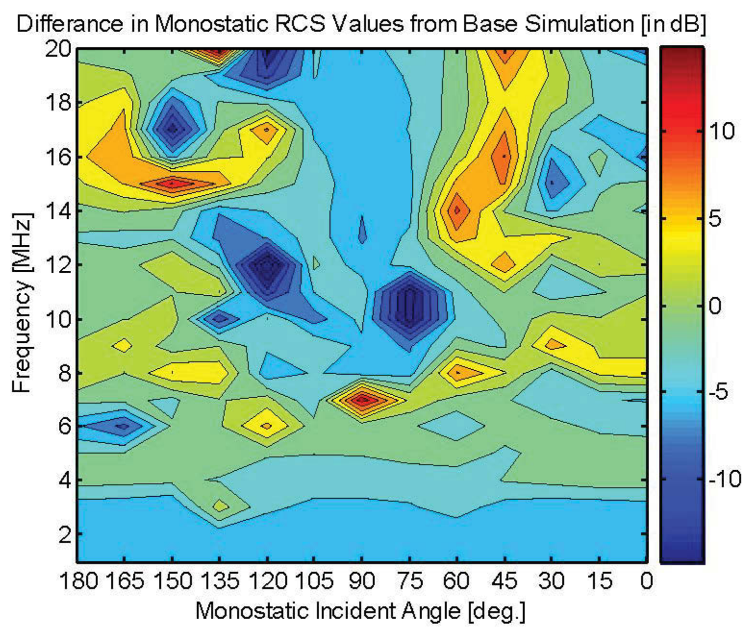

Figure 27: Difference from base simulation I ($\sigma_{4\,below}/\sigma_{base}$ in dB).

Simulation VI - Reduced Teleost Payload

The sixth set of simulations investigated Teleost payload reductions and its effect on RCS values. The normalized (to the base simulation) results are shown in Figs. 28 -30 by increasing the base model above the ground plane in1, 2 and 3 m increments.

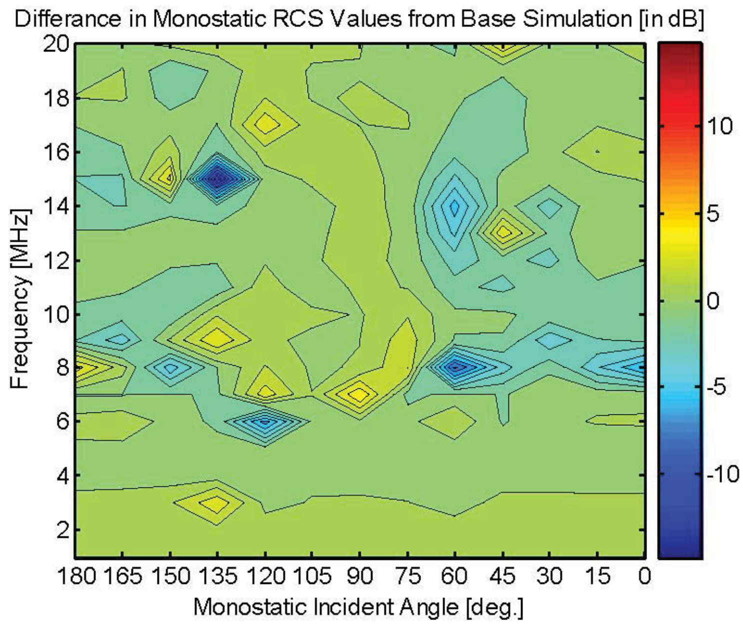

Figure 28: Difference from base simulation I ($\sigma_{1\,above}/\sigma_{base}$ in dB).

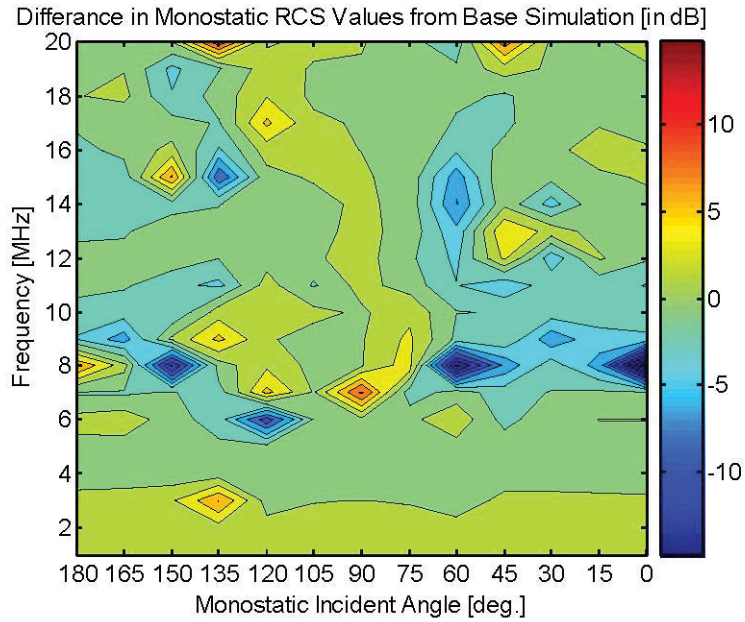

Figure 29: Difference from base simulation I ($\sigma_{2\,above}/\sigma_{base}$ in dB).

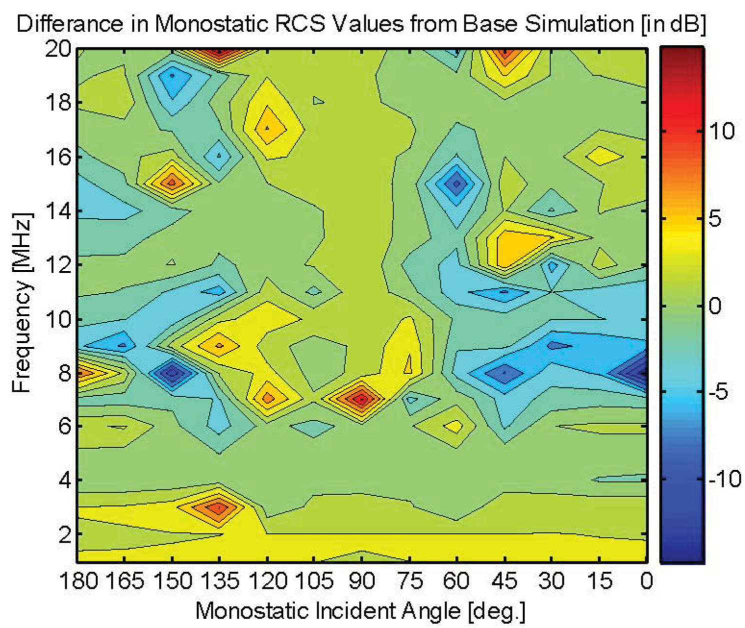

Figure 30: Difference from base simulation I ($\sigma_{3\,above}/\sigma_{base}$ in dB).

Simulation VII - Bonn Express Investigations

The sixth set of simulations compared measured and simulated monostatic RCS returns from the Bonn Express Cargo Freighter. Two simulation models were developed: the first model did not include details of cargo freight loading while the second model included the cargo storage compartments and ship displacement due to loading. The models are shown in Figs. 31 and 32. The monostatic RCS returns at 4.1 MHz are shown in Figs. 33 and 34. By modeling the freighter loading, a reasonable agreement between measured and simulated monostatic returns is achieved. In addition, Figs. 35-36 illustrate the simulated monostatic RCS return values for the Bonn Express models from 1-7 MHz. Fig. 36 illustrates the difference in RCS values for these two models.

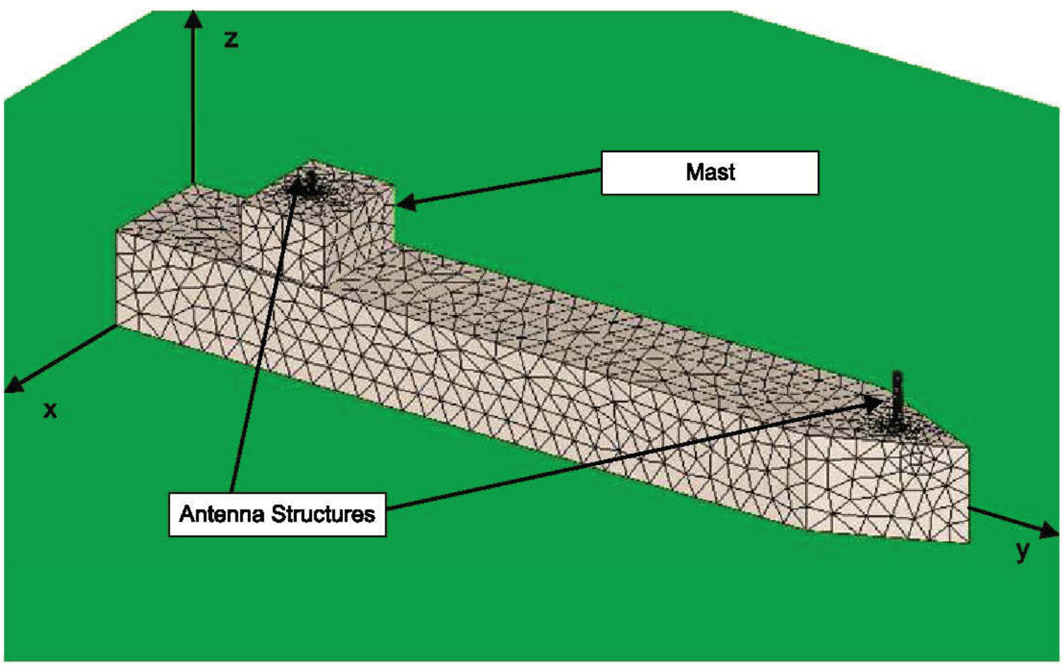

Figure 31: Bonn Express cargo freighter base model.

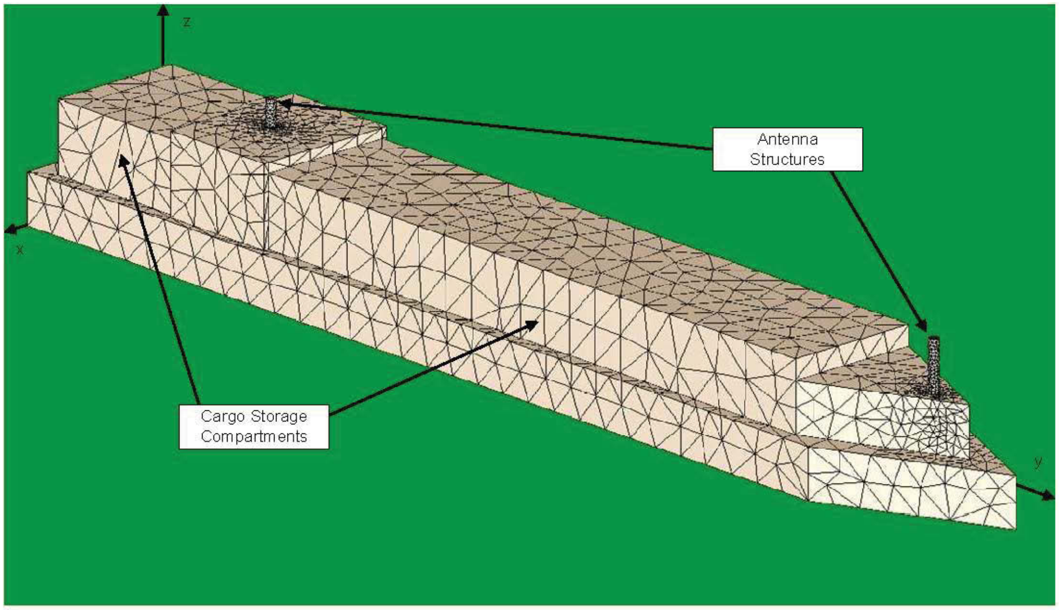

Figure 32: Bonn Express cargo freighter advanced model with cargo storage compartments and ship displacement due to loading.

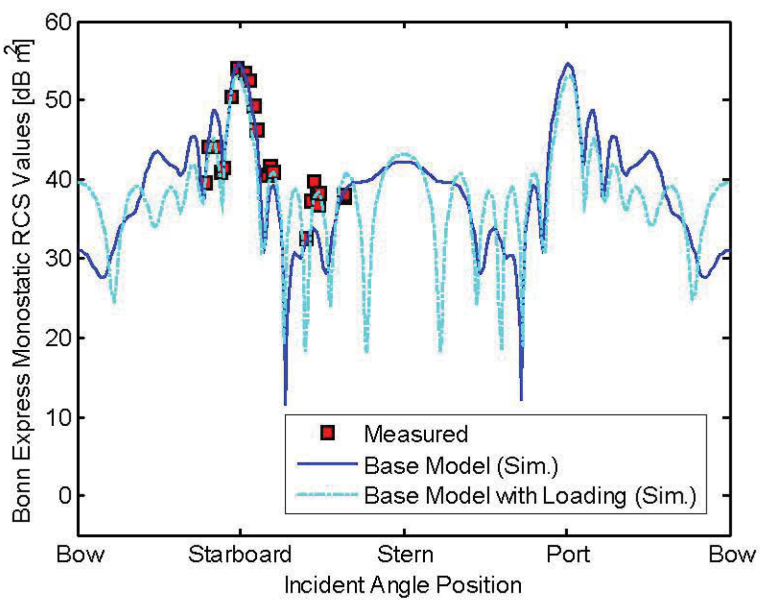

Figure 33: Comparison of measured and simulated monostatic RCS return values for the Bonn Express Freighter at 4.1 MHz. All incident angles are shown.

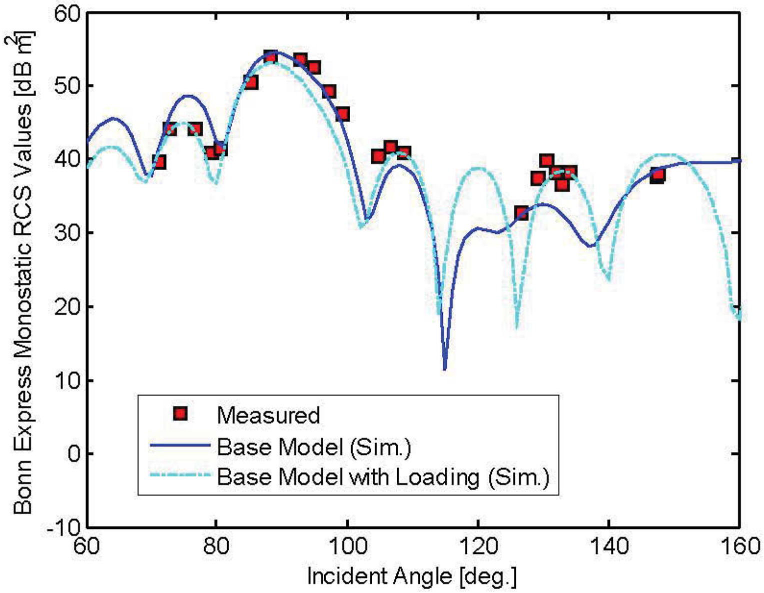

Figure 34: Comparison of measured and simulated monostatic RCS return values for the Bonn Express Freighter at 4.1 MHz. Incident angles shown from $60°$ to $160°$.

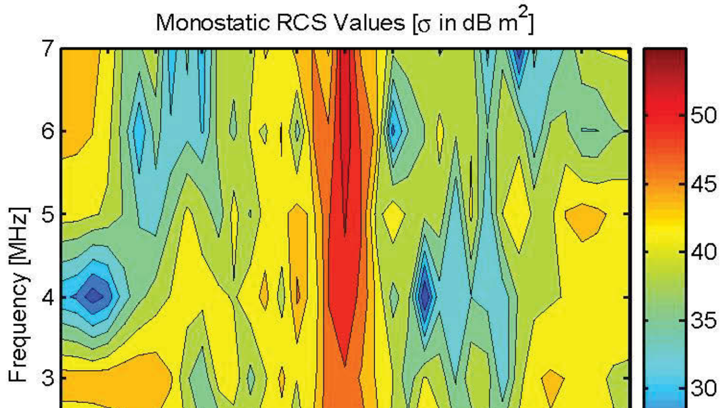

Figure 35: Simulated RCS values for the Bonn Express Freighter from 1 to 7 MHz. The base model was used (Fig. 31).

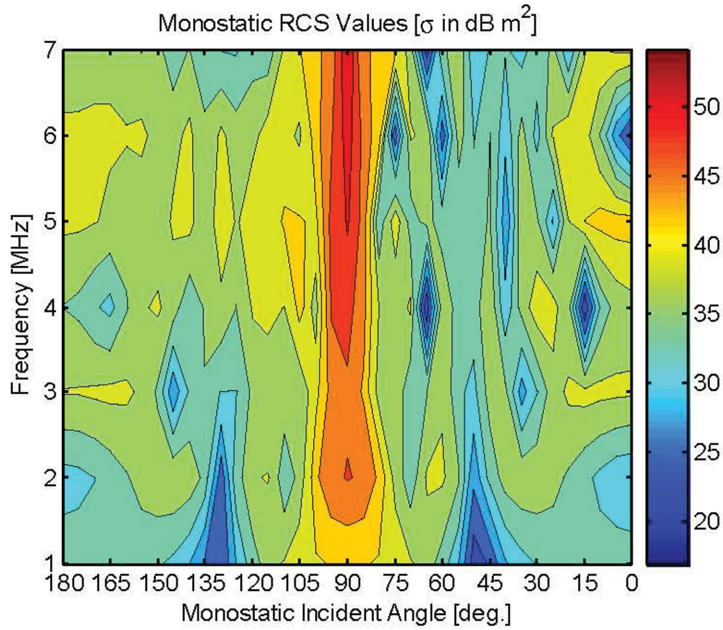

Figure 36: Simulated RCS values for the Bonn Express Freighter from 1 to 7 MHz. The detailed model that included container loading effects was used (Fig. 32).

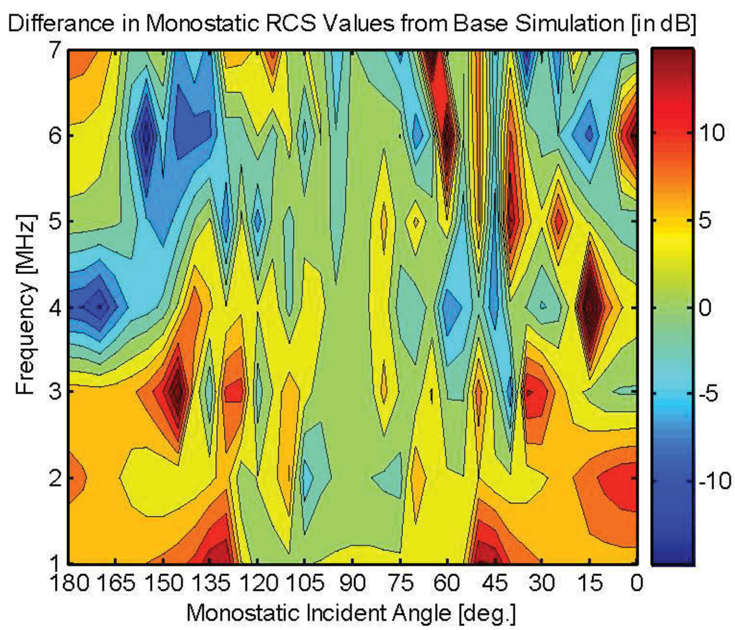

Figure 37: Difference in monostatic RCS values from the two Bonn Express models, Figs. 31 and 32. ($\sigma_{detailed}/\sigma_{base}$ in dB).

Conclusion

This work has presented monostatic and bistatic RCS simulations of the Teleost and Bonn Express Vessels. A good agreement is achieved between measured and simulated values at 4.1 MHz. With confidence in these FEKO models, the effect of pitch, roll and freighter loading was also investigated to account for such practical situations in oceanic environments.

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Monostatic and bistatic Radar Cross Sections (RCS) of Canadian Coast Guard Ship Teleost and cargo-container vessel named Bonn Express are simulated using FEKO commercial electromagnetic simulation software. A good agreement is achieved between the simulated values and the measured values supplied by DRDC Ottawa, at the radar frequency of 4.1 MHz. With confidence in these FEKO models, the effect of pitch, roll and freighter loading was then investigated to account for such practical situations in oceanic environments.

La surface équivalente radar (SER) de radars monostatiques et bistatiques à bord du navire de la Garde côtière canadienne (NGCC) *Teleost* et du transporteur de conteneurs de fret *Bonn Express* a fait l'objet de simulations à l'aide du logiciel commercial de simulation électromagnétique FEKO. Une bonne concordance est obtenue entre les valeurs simulées et les valeurs mesurées fournies par RDDC Ottawa, à la fréquence radar de 4,1 MHz. Ces modèles FEKO inspirant confiance, on a alors étudié l'effet du tangage, du roulis et de la charge des navires pour tenir compte de telles situations pratiques en milieu océanique.

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